

# NuSOnG: Physics at the Terascale

Peter Fisher, Janet Conrad

March 28, 2008

Scope and status of the project - Peter - 10'

Terascale impact of NuSOnG - Janet - 20'

We are asking the PAC to assess the physics importance of our proposed program in light of upcoming measurements from the LHC and other experiments.

We are *not* asking for approval of this program or an assessment of the feasibility of executing it.

## A Brief History...

The idea has been around for some time,

The call from the Steering Committee for “near term experiments that can be supported by an evolution of the Fermilab accelerator complex” caused the idea to gel.

The concept was endorsed by the Steering Committee:

experiment with an 800 GeV proton beam would impose approximately a five percent tax on NuMI for both Project X and SNuMI. Proton-source upgrades, particularly Project X, make possible a stronger neutrino-science program.

### FNAL Steering Group seeks input from HEP community

Director Pier Oddone has charged Deputy Director Young-Kee Kim to lead a Steering Group to develop a strategic roadmap for the accelerator-based HEP physics program at Fermilab (see [Director's Corner](#), Fermilab Today, April 17, 2007). The roadmap will outline discovery opportunities during the period before ILC construction can begin, while supporting the international R&D and engineering design for as early a start of the ILC as possible. The Steering Group, consisting of members of the US HEP community and Laboratory staff, will report to Director Oddone by August 1.

The Steering Group would like to solicit input from the HEP community as widely as possible. As part of this effort, Kim has been meeting with collaborations of experiments at Fermilab, will give a report on the Steering group's work at the Fermilab and SLAC Users Meetings on June 6 and June 7, respectively, and will conduct Town Hall meetings on the same days. To provide input, please [email](#) Kim a note or a letter with your thoughts.

The Steering Group would also like to hear ideas from the community on near-term experiments that can be supported by an evolution of the Fermilab accelerator complex. If you have suggestions, please write up a single-page sketch consisting of the physics case, back-of-envelope discussion of accelerator requirements, and a brief detector description. Please send your input by Monday, June 11.

You can find the charge, membership and activities of the Steering Group [here](#).

As a next step we submitted an EOI in Autumn, 2007

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Available at <http://www-nusong.fnal.gov>

From Nov. 2, 2007 PAC:

1. Clarify capabilities for Terascale physics, especially taking into account present and planned experiments.
2. How do you plan to measure  $\Delta x F_3$ ?

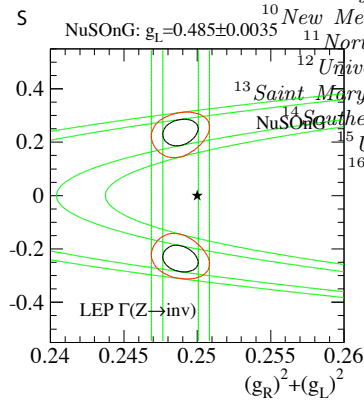
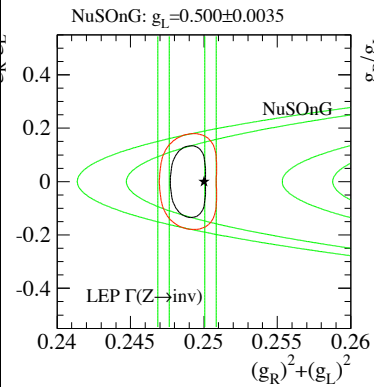
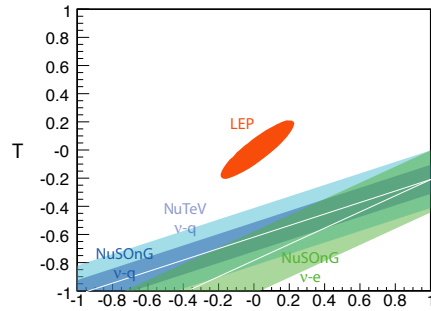
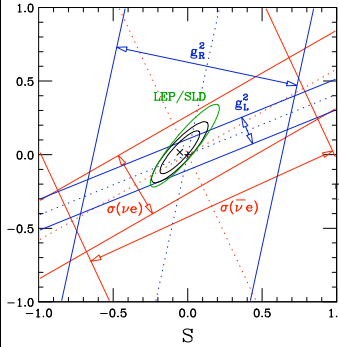
From the Director:

1. What else can run in a future Tevatron fixed target program?

# In response to the first question, we have prepared a Physical Review D article,

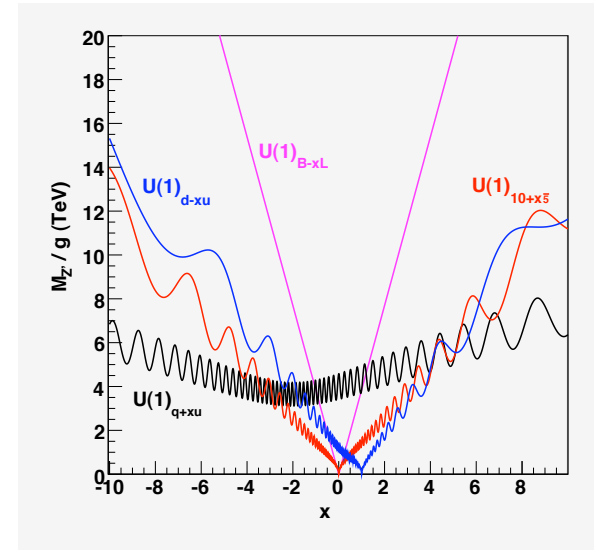
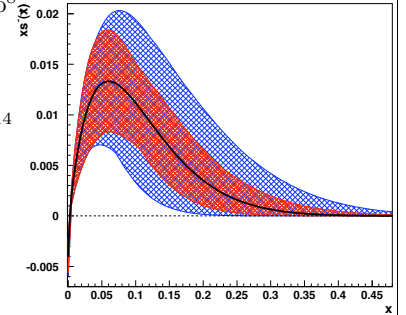
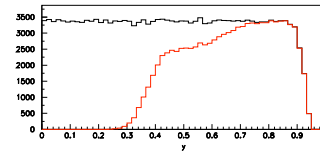
## Terascale Physics Opportunities at a High Statistics, High Energy Neutrino Scattering Experiment: NuSOng

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J. Jenkins<sup>11</sup>, G. Karagiorgi<sup>3</sup>, T.R. Kobilarcik<sup>4</sup>, S. Kopp<sup>15</sup>, G. Kyle<sup>10</sup>, W.A. Loinaz<sup>1</sup>, D.A. Mason<sup>4</sup>,  
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J.F. Owens<sup>5</sup>, S.F. Pate<sup>10</sup>, A. Pronin<sup>16</sup>, W.G. Seligman<sup>3</sup>, M.H. Shaevitz<sup>3</sup>, H. Schellman<sup>11</sup>, I. Schienbein<sup>7</sup>,  
M.J. Syphers<sup>4</sup>, T.M.P. Tait<sup>2,11</sup>, T. Takeuchi<sup>16</sup>, C.Y. Tan<sup>4</sup>, R.G. Van de Water<sup>6</sup>, R.K. Yamamoto<sup>8</sup>, J.Y. Yu<sup>14</sup>



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(Dated: March 20, 2008)



This has been submitted to PRD.

Today, Janet will address the first question.

We are planning a second publication on the impact on QCD of NuSOnG.

Since Nov. 2, we have also

1. Nearly completed a full GEANT4 simulation of the experiment.
2. Made considerable progress fleshing out the method for calibrating the neutrino beam flux using inverse muon decay
3. Developed a much better understanding of the beam spatial profile and energy spectrum.

We will prepare a Letter of Intent for a subsequent PAC.

Our detector design draws on the heritage of FMMF, CDHS, CHARM and CCFR/NuTeV.

NuSOnG combines and advances the best ideas of these experiments:

1. High granularity,  $X_0/4$
2. Simple, robust, design
3. Large mass (3 kt, 6 times CHARM II), isoscalar target
4. Modularity: active elements could be fabricated at universities for assembly at Fermilab
5. Low risk: well known elements that can be engineered for cost
6. High energy, pure beam (20 times NuTeV):
  - neutrinos:  $1.5 \times 10^{20}$  POT over 5 years
  - anti-neutrinos:  $0.5 \times 10^{20}$  POT

NuSOnG will study the reactions

$$\nu_{\mu} + e^{-} \rightarrow \nu_{\mu} + e^{-}$$

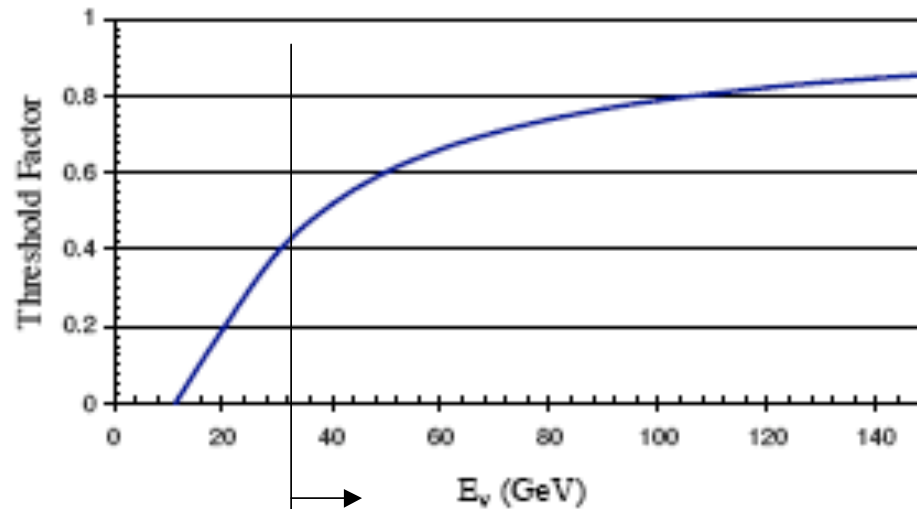
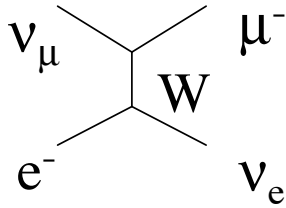
$$\bar{\nu}_{\mu} + e^{-} \rightarrow \bar{\nu}_{\mu} + e^{-}$$

$$\nu_{\mu} + q \rightarrow \nu_{\mu} + X$$

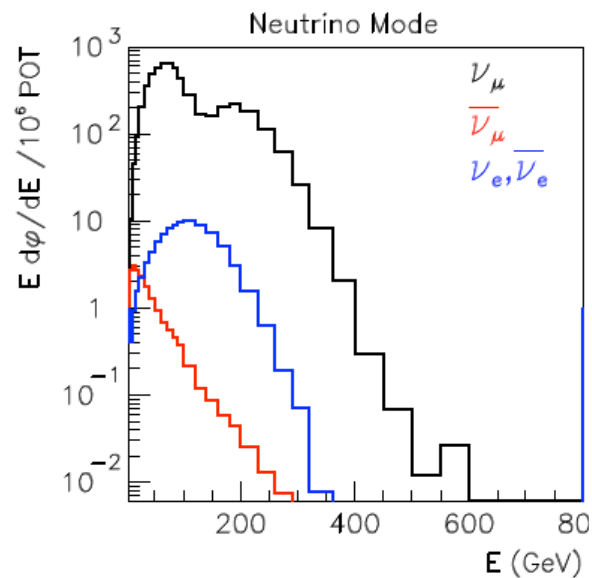
$$\bar{\nu}_{\mu} + q \rightarrow \bar{\nu}_{\mu} + X$$

with better than 1% precision

Why do we need a Tev-based beam?



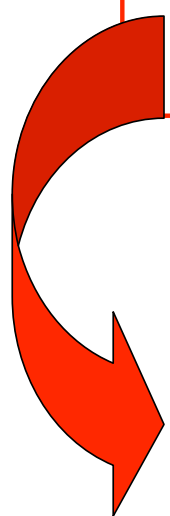
Want flux above  $\sim 30$  GeV  
Need no flux below!



Tev-based beam gives high energy flux,

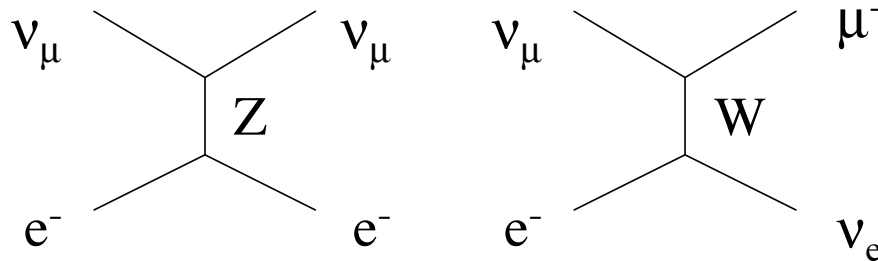
The strong cutoff at low energy is due to the energy-angle correlation in  $\pi$  decay

## Very high statistics!



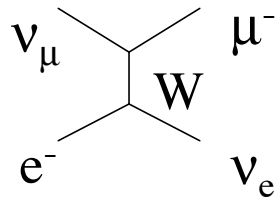
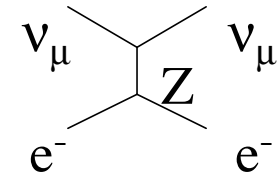
600M	$\nu_\mu$ CC Deep Inelastic Scattering
190M	$\nu_\mu$ NC Deep Inelastic Scattering
75k	$\nu_\mu$ electron NC elastic scatters
700k	$\nu_\mu$ electron CC quasielastic scatters (IMD)
33M	$\bar{\nu}_\mu$ CC Deep Inelastic Scattering
12M	$\bar{\nu}_\mu$ NC Deep Inelastic Scattering
7k	$\bar{\nu}_\mu$ electron NC elastic scatters
0k	$\bar{\nu}_\mu$ electron CC quasielastic scatters

A unique opportunity for these channels!

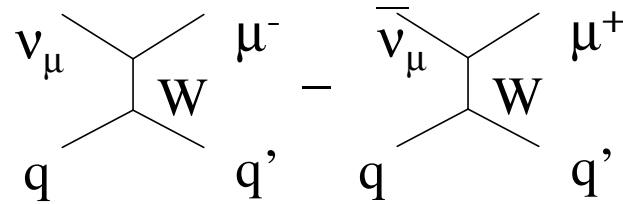
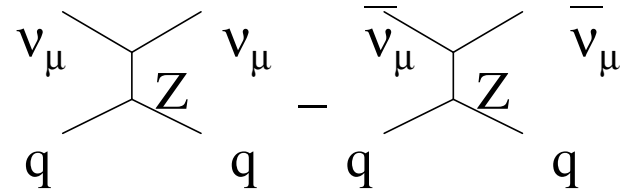


NuSOnG will work with **ratios**....

**New!**



Purely leptonic



NuTeV-style  
“Paschos-Wolfenstein”

Expected errors  
0.7% conservative,  
0.4% best case

0.4% conservative  
0.2% best case

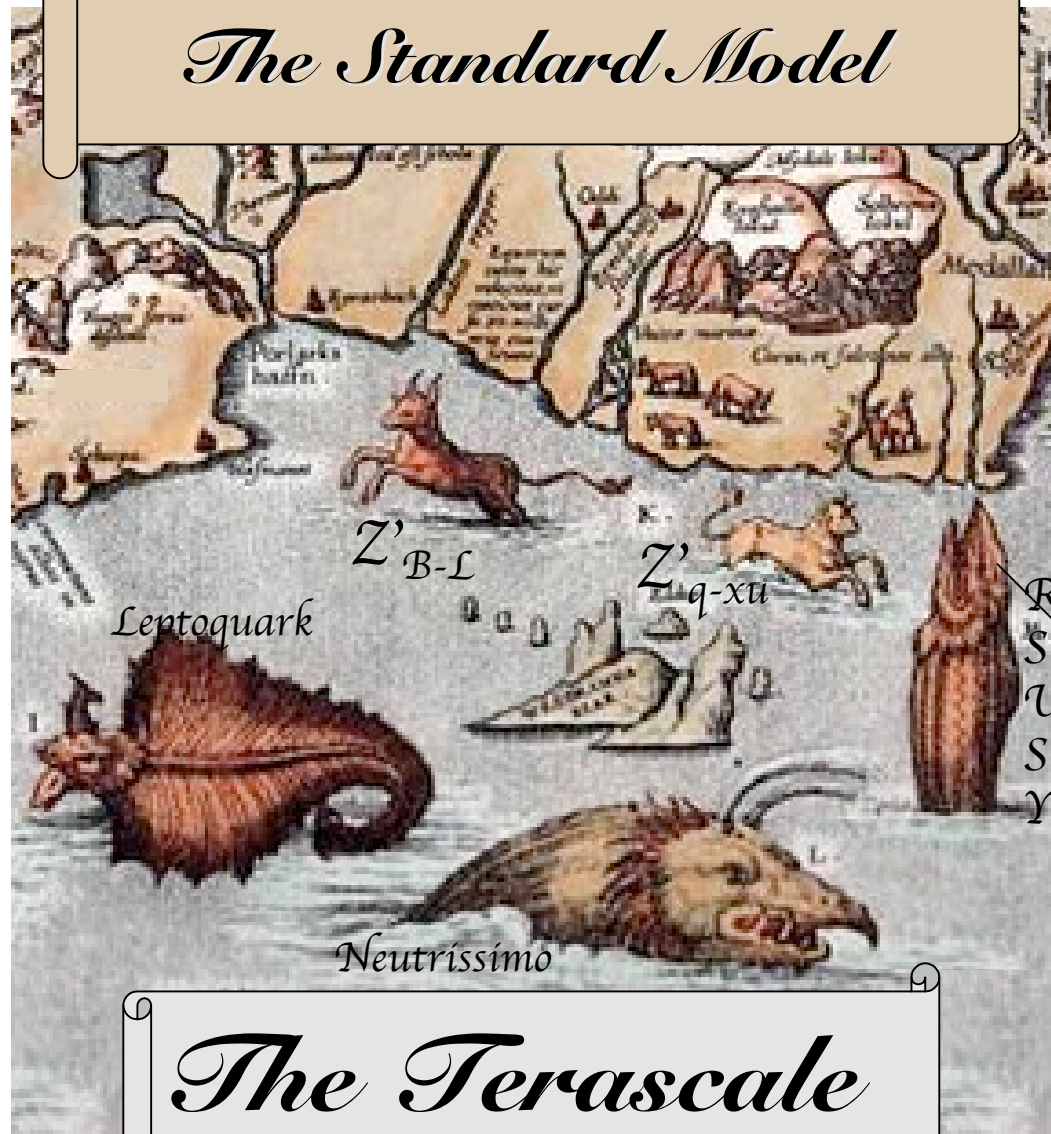
**Our case is based on the conservative estimates**

# The Terascale Physics Case for NuSOnG

At the energies  $\gtrsim 1$  TeV,  
we expect rich new phenomena to appear.

But since this is *terra incognita*,  
We are faced with the conundrum...

## *The Standard Model*



## *The Terascale*

Which ~~monster~~ shall we discuss?  
**model**

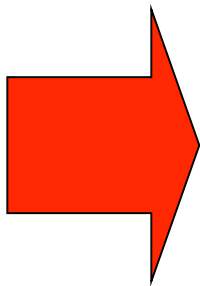
Following the structure of our paper:

- 1) Reach within general classes of New Physics
- 2) Reach within specific models and scenarios

What we show:

There are cases where we have overlapping reach with LHC  
or other experiments

There are cases where our reach is unique.



We provide valuable information beyond  
the present program in both cases

From our paper:

5 general classes of new physics searches...

(Table V of paper)

Oblique Corrections

Neutrino-lepton NSIs

Neutrino-quark NSIs

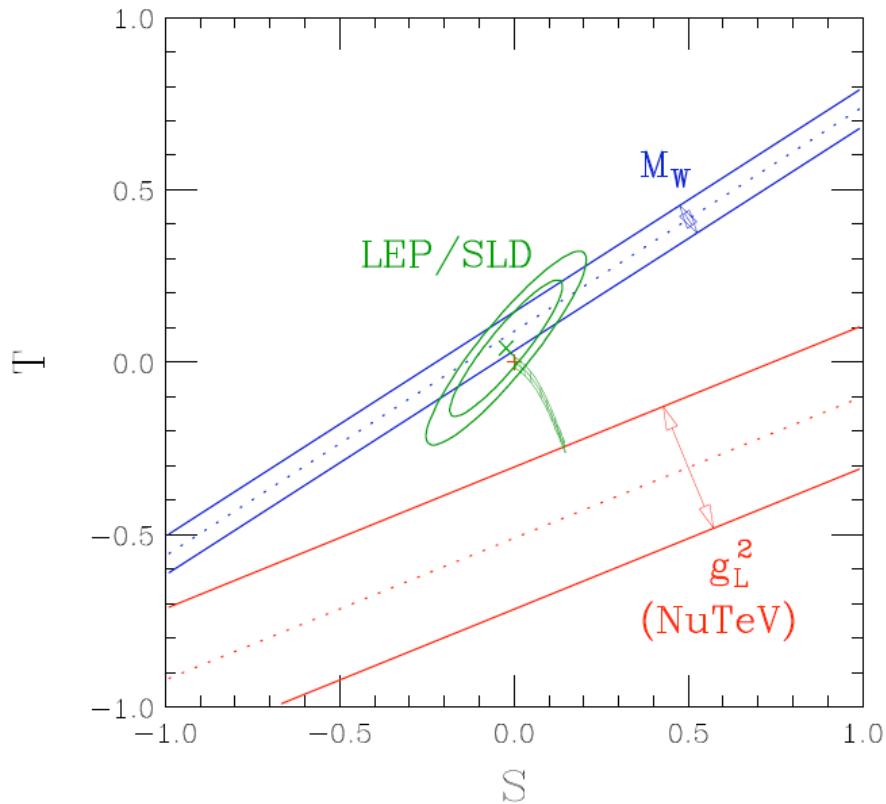
Nonuniversal couplings

Right-handed coupling to the Z

... “generic ways” that new physics might show up

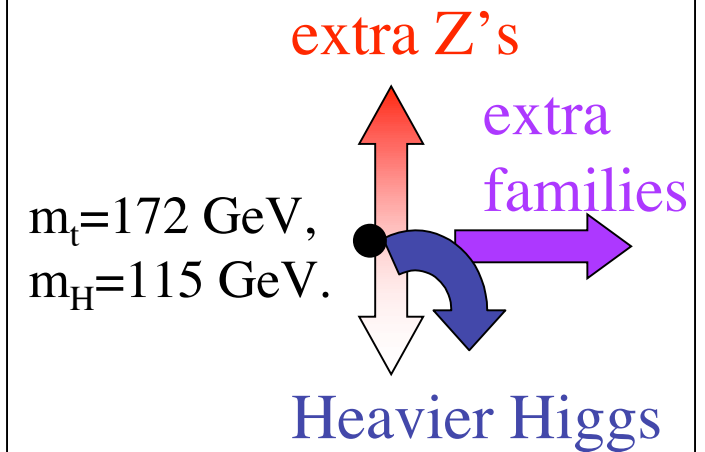
# New physics through oblique corrections

Take  $\sin^2 \theta_W$  and  $\rho$  and map them to  
**S = weak isospin conserving**  
**T = weak isospin violating**



very roughly:

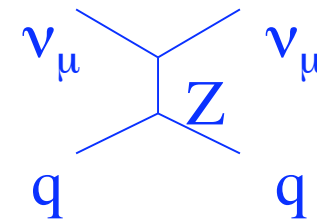
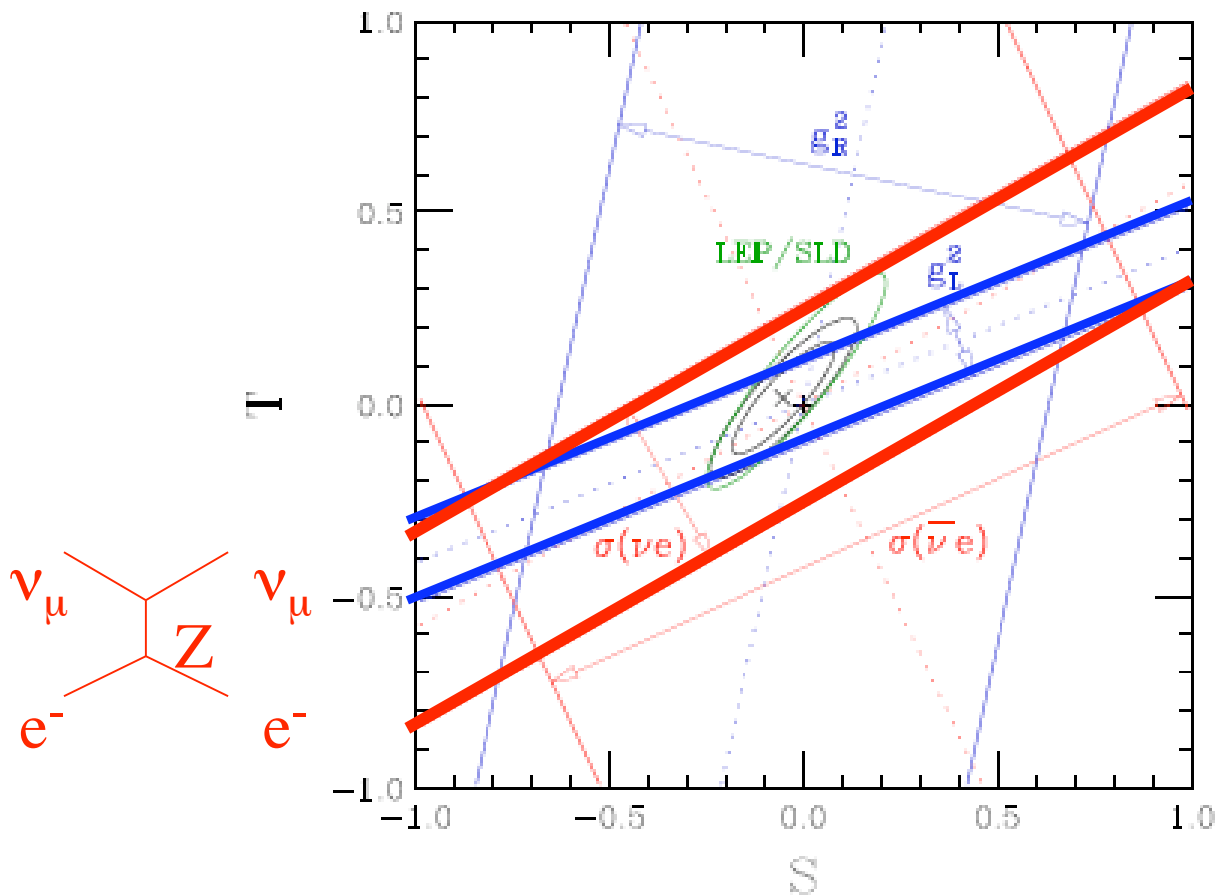
T



S

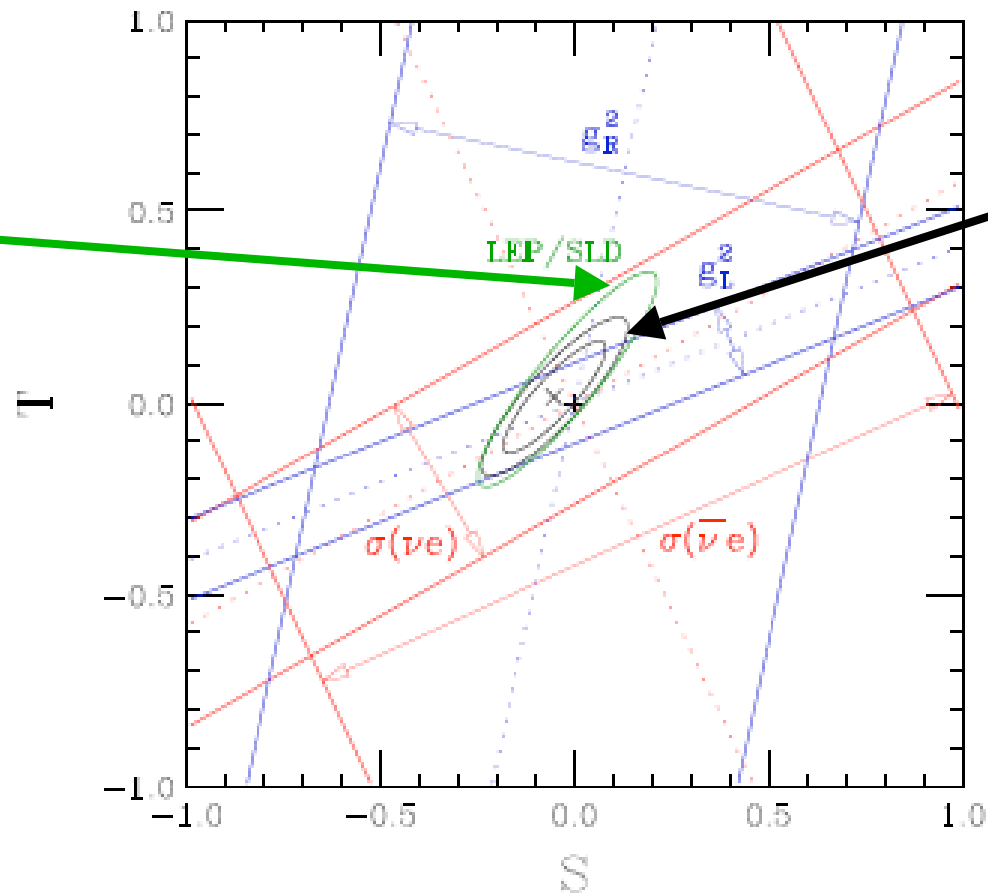
Consider four  
NuSONG  
measurements:

$$\begin{aligned}
 1) \quad & \sigma(\nu, e), & 3) \quad & g_L^2 = (2g_L^\nu g_L^u)^2 + (2g_L^\nu g_L^d)^2 \\
 2) \quad & \sigma(\bar{\nu}, e), & & = \rho^2 \left( \frac{1}{2} - \sin^2 \theta_W + \frac{5}{9} \sin^4 \theta_W \right), \\
 4) \quad & & & g_R^2 = (2g_L^\nu g_R^u)^2 + (2g_L^\nu g_R^d)^2 \\
 & & & = \rho^2 \left( \frac{5}{9} \sin^4 \theta_W \right).
 \end{aligned}$$



The  $\sigma(\nu, e)$  and  $g_L^2$  measurements are the strongest with the initial run-plan

Present  
status



If NuSOng  
agrees with  
the SM

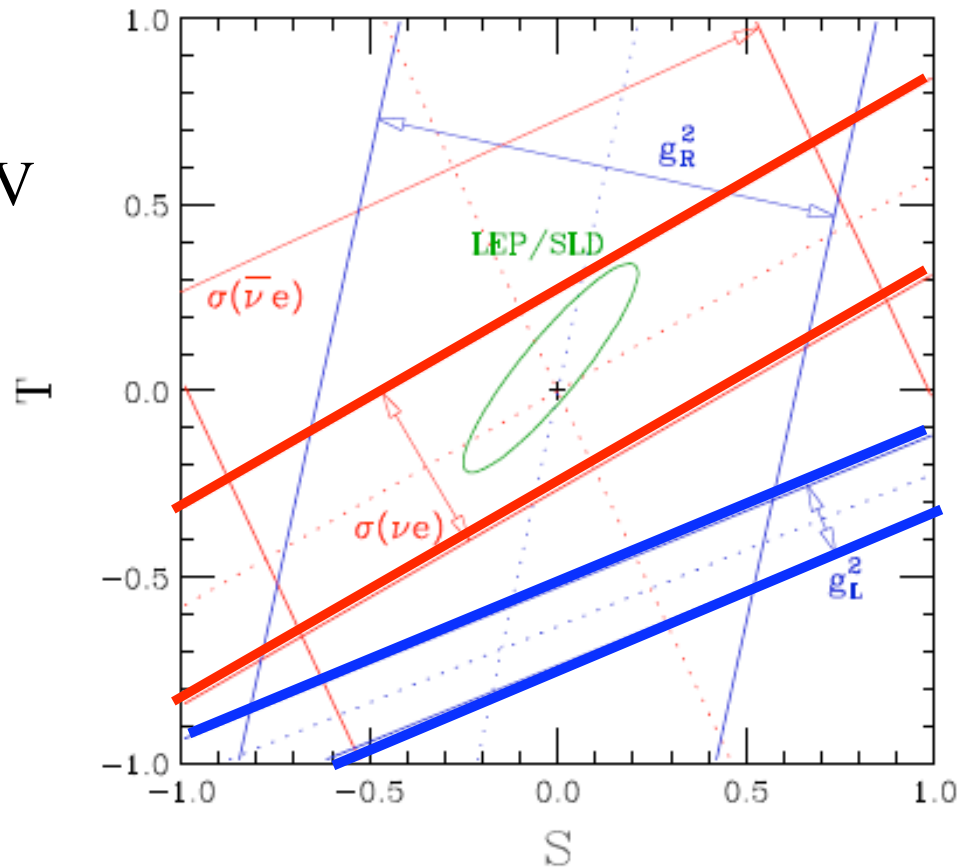
NuSOng  
improves  
the result  
by  $\sim 25\%$

But of course the more interesting case is...

disagreement with SM!

A “realistic” possibility:  
NuSOnG agrees with NuTeV

a  $6\sigma$  deviation from the SM  
in  $g_L^2$  only

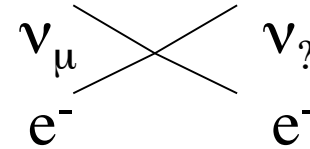


(This particular case, where all other measurements agree with the SM,  
is a triplet Leptoquark)

## Non-standard interactions (NSIs):

First, the purely leptonic case:

Neutrino-lepton NSI



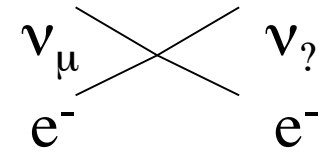
New physics is characterized by

- The mass scale of the new physics ( $\Lambda$ )
- The probability of left vs. right-handed coupling to the  $e$ , described by a mixing angle ( $\cos \theta$ )
- The flavor of the outgoing neutrino (“ $\alpha$ ” flavor)  
*i.e.* “pseudo-elastic” neutrino scattering

Look for this new physics via:

- change cross section
- angular dependence of outgoing electron

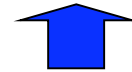
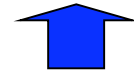
# NSI reach for **neutrino-lepton scattering**



$$\mathcal{L}_{\text{NSI}}^e = + \frac{\sqrt{2}}{\Lambda^2} \left[ \bar{\nu}_\alpha \gamma_\sigma P_L \nu_\mu \right] \left[ \cos \theta \bar{e} \gamma^\sigma P_L e + \sin \theta \bar{e} \gamma^\sigma P_R e \right]$$

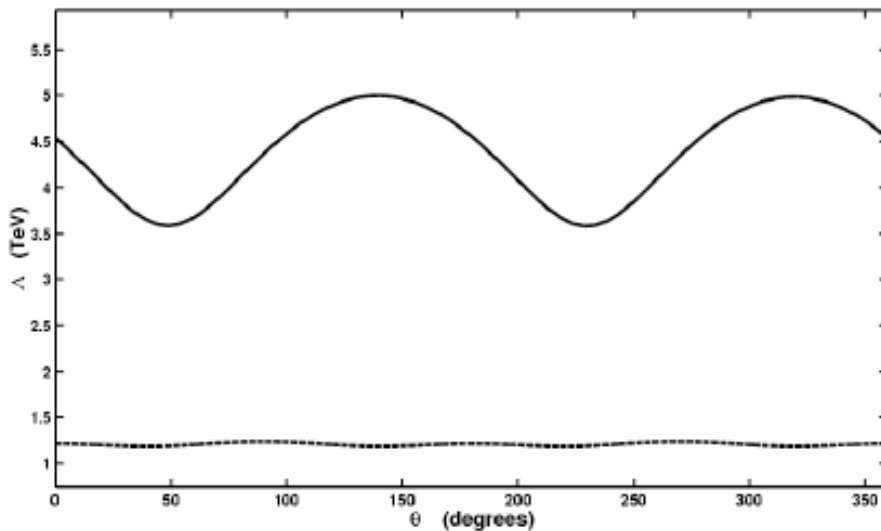


mass  
scale      outgoing  
              flavor



Relative mixture  
of handedness

$\Lambda$



$\theta$

95% CL sensitivity



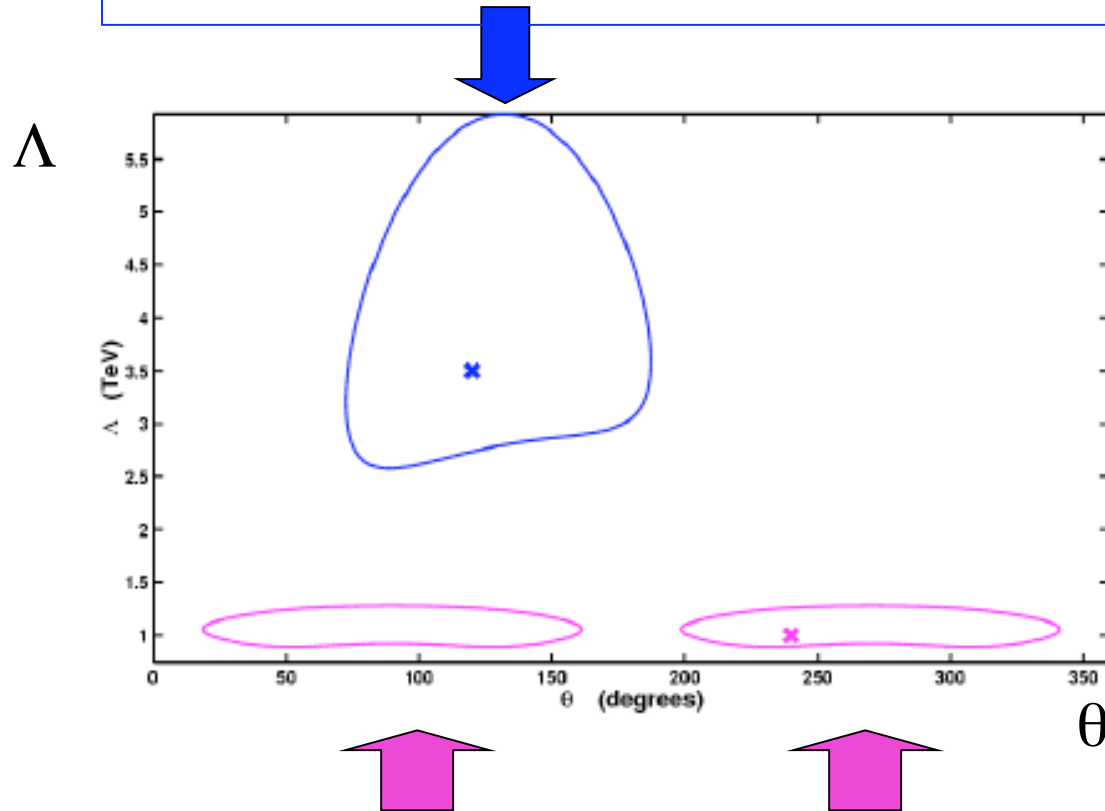
if  $\alpha = \text{muon flavor}$   
~4.5 TeV



if  $\alpha \neq \text{muon flavor}$   
~1.25 TeV

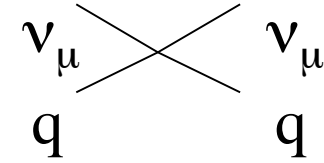
But we might **see a signal!**

Assume  $\Lambda=3.5$  TeV,  $\theta=2\pi/3$ ,  $\alpha=\mu\dots$   
this is the  $2\sigma$  contour from NuSOnG



Assume  $\Lambda=1$  TeV,  $\theta=4\pi/3$ ,  $\alpha\neq\mu\dots$   
these are the  $2\sigma$  contours from NuSOnG

What about neutrino-quark NSI's ?



We consider only the flavor conserving case,  $\alpha=\mu$

There is a characteristic mass scale  $\Lambda$

Sensitivity ranges from  $\sim 3$  to  $7$  TeV

coupling:	present constraint	NuSONG factor improvement
uL	$<0.001$	$\times 2$
dL	$<0.0008$	$\times 2$
uR	$<0.002$	$\times 1.75$
dR	$<0.004$	$\times 1.83$

# Non-universal couplings & signs of a generic “neutrissimo”

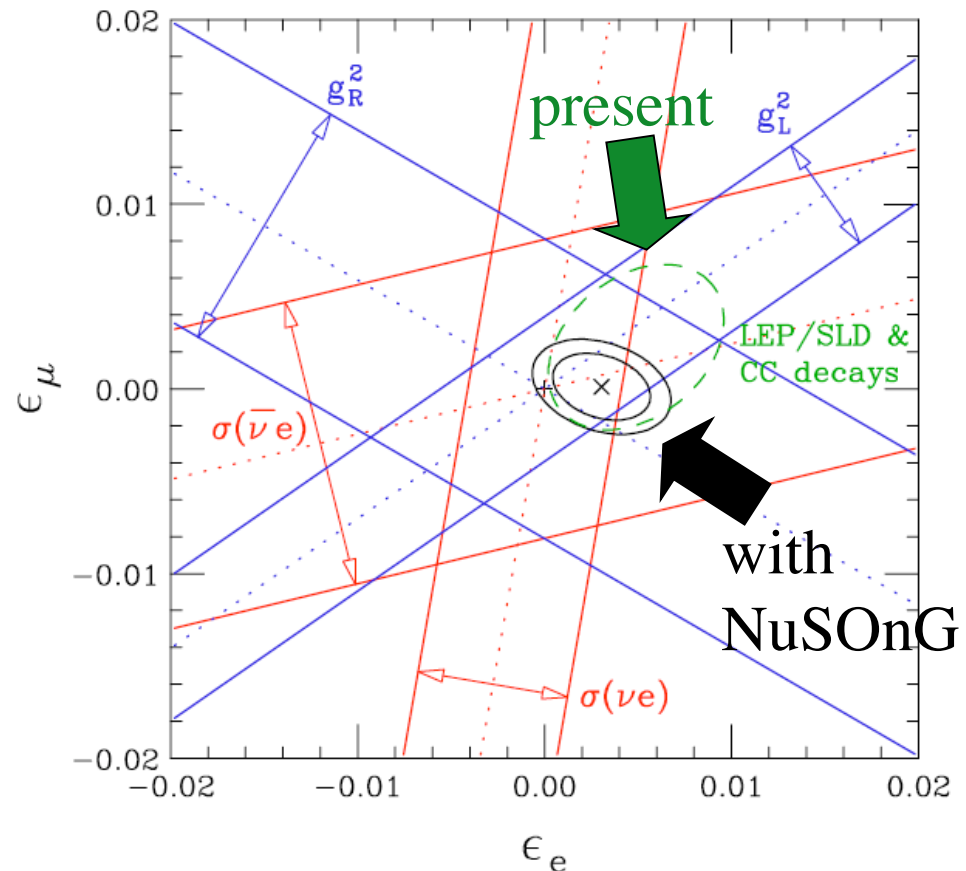
$$\nu_\ell = \nu_{\ell,\text{light}} \cos \theta_\ell + \nu_{\ell,\text{heavy}} \sin \theta_\ell ,$$

defining...

$$\epsilon_\ell \equiv 1 - \cos^2 \theta_\ell .$$

The CC coupling is  
modified by:  $\frac{\epsilon_\ell}{2}$

The NC coupling is  
modified by  $\epsilon_\ell$



NuSOnG improves constraints by  $\sim 30$  to  $75\%$

## Conclusions on the general discussion of NuSOnG's Terascale reach...

- Mass reach: 1 to 7 TeV
- Unique information on the couplings
- Many ways to probe for new physics with high sensitivity.

*We have been conservative in our assumed sensitivity.  
It is likely that we can do better than this.*



***Onward to some  
specific models!***

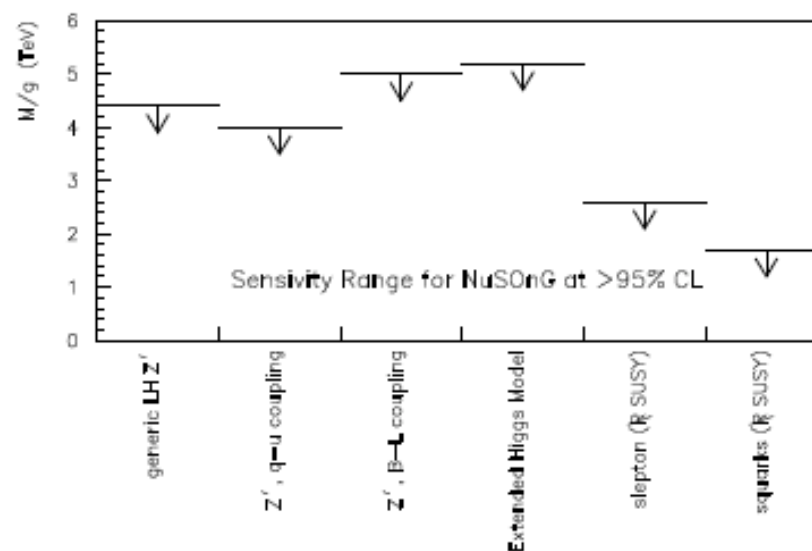
# NuSOnG in the Context of Specific “Typical” Models

Model	Contribution of NuSOnG Measurement
Typical $Z'$ Choices: $(B - xL), (q - xu), (d + xu)$	At the level of, and complementary to, LEP II bounds.
Extended Higgs Sector	At the level of, and complementary to $\tau$ decay bounds.
R-parity Violating SUSY	Sensitivity to masses $\sim 2$ TeV at 95% CL. Improves bounds on slepton couplings by $\sim 30\%$ and on some squark couplings by factors of 3-5.
Intergenerational Leptoquarks with non-degenerate masses	Accesses unique combinations of couplings. Also accesses coupling combinations explored by $\pi$ decay bounds, at a similar level.

TABLE VI: Summary of NuSOnG’s contribution in the case of specific models

Again, typical mass reach is  
1 to 5 TeV,  
depending on the model

Choose two examples...

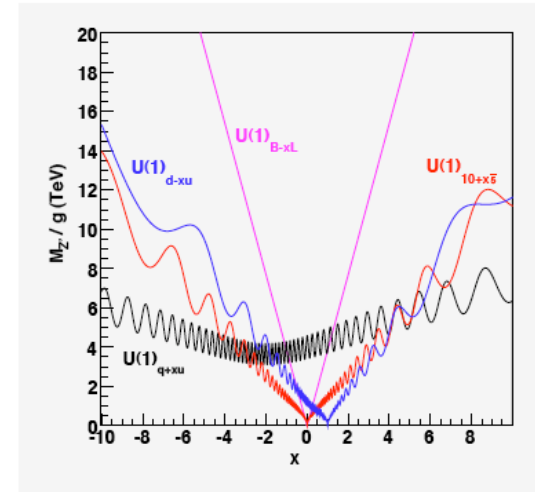


## Heavy Z' Models

Four examples of types of couplings...

	$U(1)_{B-xL}$	$U(1)_{q+xu}$	$U(1)_{10+x\bar{5}}$	$U(1)_{d-xu}$
$\nu_{\mu L}, e_L$	$-x$	$-1$	$x/3$	$(-1+x)/3$
$e_R$	$-x$	$-(2+x)/3$	$-1/3$	$x/3$

Reach extends to many TeV,  
depending on the  $U(1)'$  symmetry.



## R-parity Violating SUSY

Coupling	95% NuSOnG bound	current 95% bound
$ \lambda_{121} $	0.03	0.05 ( $V_{ud}$ )
$ \lambda_{122} $	0.04	0.05 ( $V_{ud}$ )
$ \lambda_{123} $	0.04	0.05 ( $V_{ud}$ )
$ \lambda_{231} $	0.05	0.07 ( $\tau$ decay)
$ \lambda'_{211} $	0.05	0.06 ( $\pi$ decay)
$ \lambda'_{212} $	0.06	0.06 ( $\pi$ decay)
$ \lambda'_{213} $	0.06	0.06 ( $\pi$ decay)
$ \lambda'_{221} $	0.07	0.21 ( $D$ meson decay)
$ \lambda'_{231} $	0.07	0.45 ( $Z \rightarrow \mu^+ \mu^-$ )

20% to 40%  
} improvements  
on LLE

Factors of 3 to 5  
} improvement!  
on LQD

But by the time NuSOnG runs,  
chances are something new will have been seen...



Through NuSOnG's measurements,  
we can help identify the new physics

### One Example Scenario: A Chiral 4th Generation Family

(Four Generations and Higgs Physics, hep-ph/0706.3718  
G. D. Kribs, Y. Plehn, M. Spannowsky, T.M.P. Tait)

## LHC:

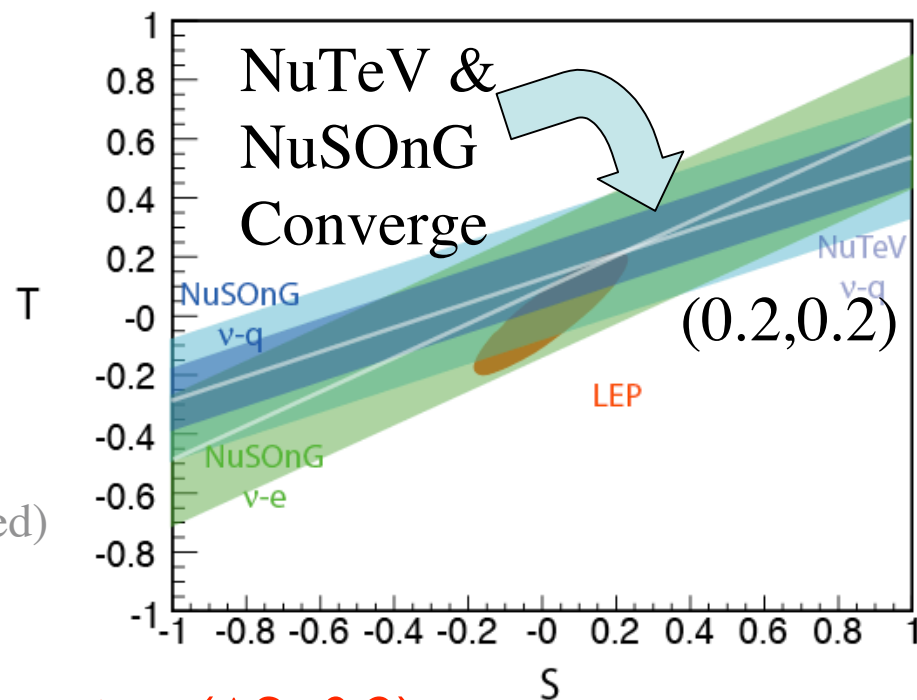
- Highly enhanced  $H \rightarrow ZZ$
- The Higgs mass,  
lets say 300 GeV
- complex decay modes  
(e.g. 6W's and 2 b's)

And what it doesn't...

- Measure mass of new quarks
- Observe new charged leptons  
(off mass shell Drell-Yan produced)
- Reconstruct the decay modes fully

## NuSONG:

QCD explanation for NuTeV is found,  
allowing NuTeV to be corrected

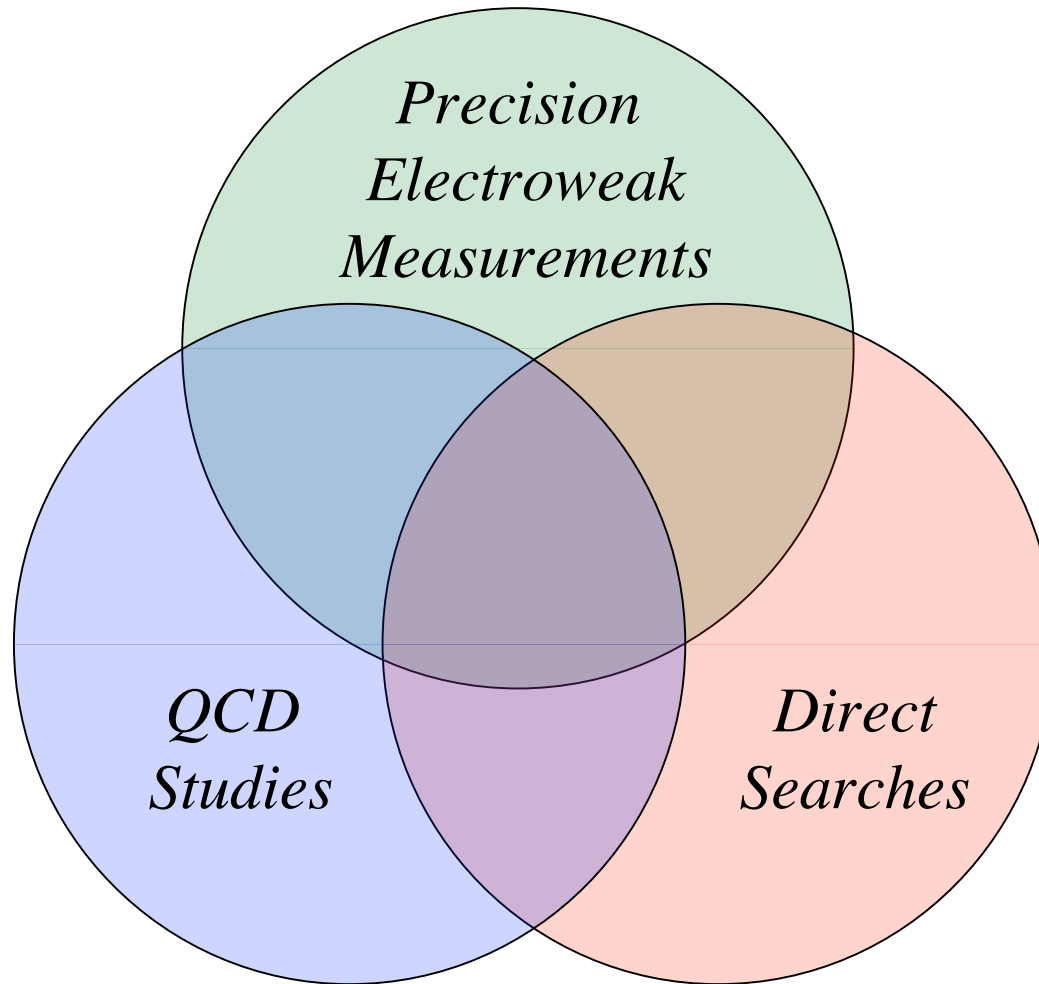


**A Chiral 4th generation ( $\Delta S=0.2$ )  
with isospin violation ( $\Delta T=0.2$ )**

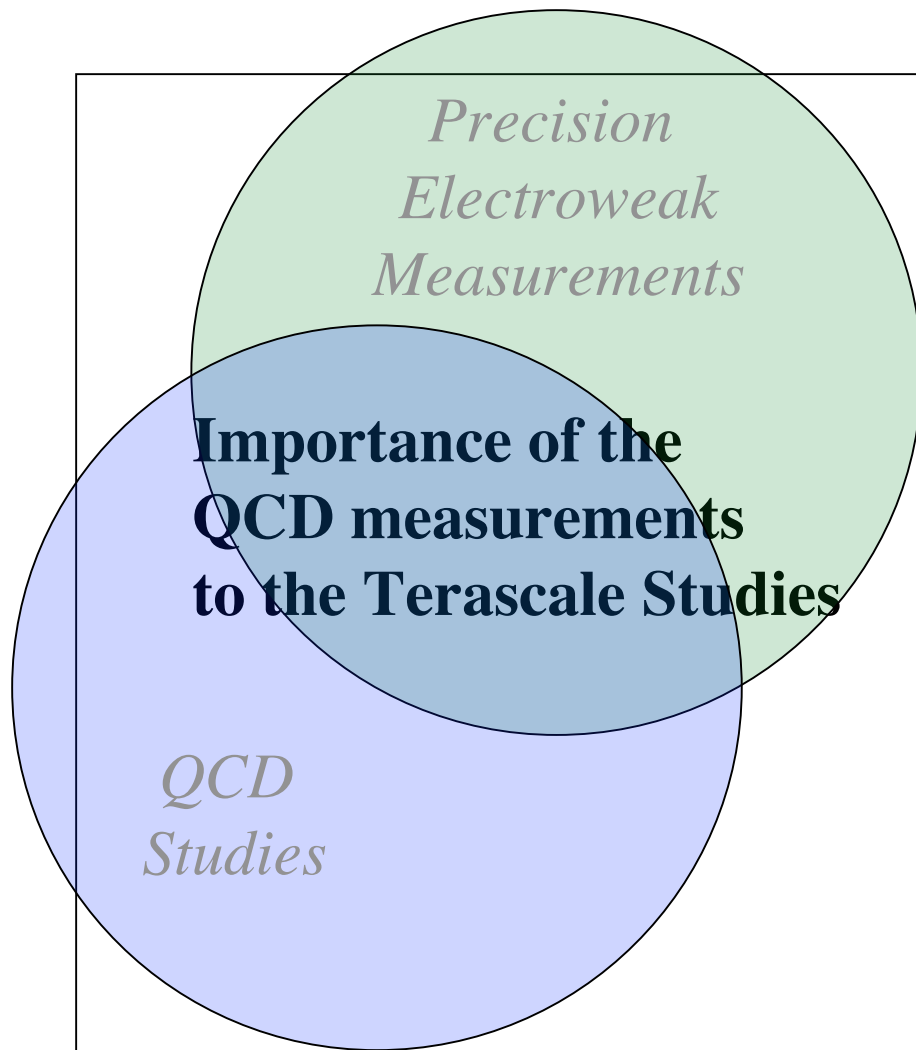
Pick your favorite LHC BSM model, I'll show how we help...

# The Terascale Program and Other NuSOnG Physics Goals

NuSOnG has a rich physics program, with interlinked parts



The Terascale Goals provide nice examples  
of how all these parts work together to lead to discovery...



$$\frac{\nu_\mu \begin{array}{c} \diagup \quad \diagdown \\ \text{Z} \\ \diagdown \quad \diagup \end{array} q}{q} - \frac{\bar{\nu}_\mu \begin{array}{c} \diagup \quad \diagdown \\ \text{Z} \\ \diagdown \quad \diagup \end{array} q}{q}$$

$$\frac{\nu_\mu \begin{array}{c} \diagup \quad \diagdown \\ \text{W} \\ \diagdown \quad \diagup \end{array} q}{q} - \frac{\bar{\nu}_\mu \begin{array}{c} \diagup \quad \diagdown \\ \text{W} \\ \diagdown \quad \diagup \end{array} q}{q}$$

NuTeV-style  
“Paschos-Wolfenstein”

This requires a set of self-consistent  
Structure Functions measured on  
the target material.

The question...

Is this:

$$\begin{array}{c} \nu_\mu \\ \diagup \quad \diagdown \\ \quad \quad W \\ \diagdown \quad \diagup \\ q \end{array} \mu^- - \begin{array}{c} \bar{\nu}_\mu \\ \diagup \quad \diagdown \\ \quad \quad W \\ \diagdown \quad \diagup \\ q \end{array} \mu^+$$

$q' \qquad q'$

being modeled correctly?

NuTeV measures the parton distributions on iron,  
with these assumptions:

1.  $F_2^\nu = F_2^{\bar{\nu}}$
2.  $R_L$  from charged lepton scattering applies to  $\nu$  and  $\bar{\nu}$

Our goal on NuSOnG:

A global fit to  $F_2^\nu$ ,  $F_2^{\bar{\nu}}$ ,  $xF_3^\nu$ ,  $xF_3^{\bar{\nu}}$ ,  $R_L^\nu$ ,  $R_L^{\bar{\nu}}$

*We are investigating  
our capability*

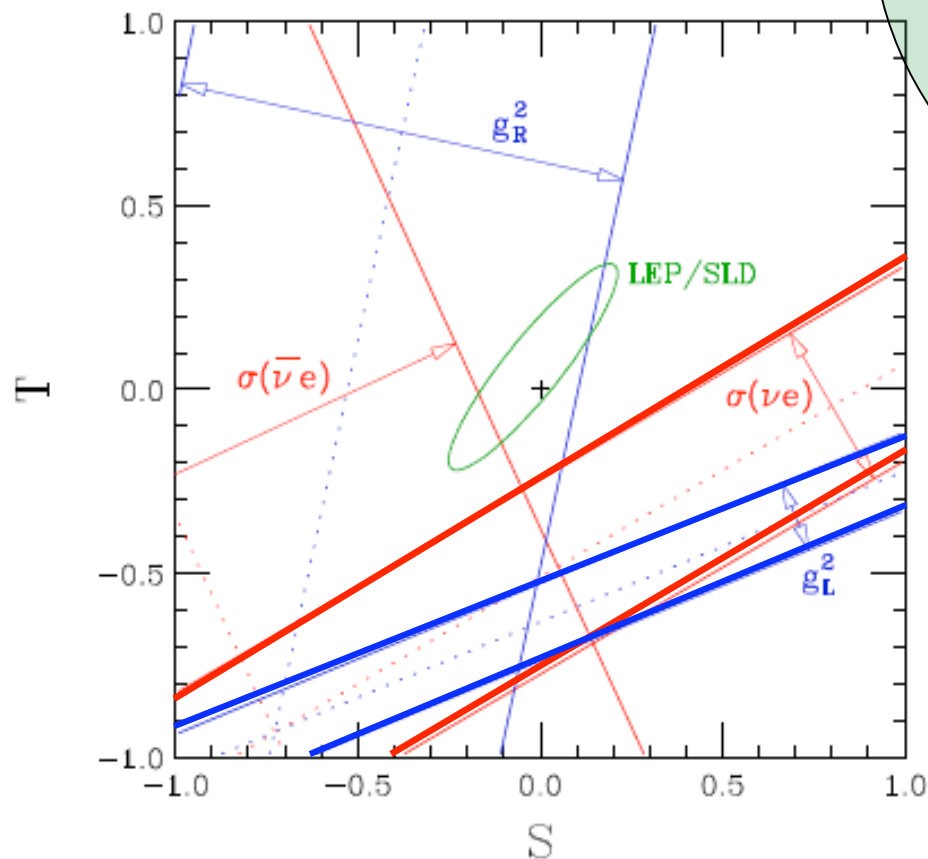
(Technique was developed by CCFR student C. McNulty,  
which was limited by statistics.)

In the meantime, the paper describes:

1. The issues
2. The plan for the global fit
3. A discussion of outside constraints on isospin violation
4. A discussion of the strange sea measurement.

An example:  
Neutrissimos.

Say we observe...  
both  $g_L^2$  and  $\sigma(\nu e)$  are offset

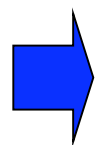


*Precision  
Electroweak  
Measurements*

**Value of the additional  
direct searches  
to the Terascale Studies**

*Direct  
Searches*

This is a signal consistent with  
modified  $\epsilon_\mu$   
i.e. nonuniversal couplings.

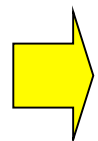


Non-universal couplings may be due to  
mixing with an  $\sim 100$  GeV neutrissimo.



This neutrissimo may be very hard to see at LHC  
due to low production rates.

But,



nonuniversal couplings manifest as non-unitarity  
in the three neutrino mixing matrix



& the heavy neutrissimo may have a lighter partner  
that can be produced in meson decays

NuSOnG can search for both effects!

## Nonunitarity of the 3 neutrino mixing matrix

$$\sum_j |U_{\alpha j}|^2 = 1 - X_\alpha,$$

hep-ph/0705.0107

$$P_{\alpha\alpha}^{general} = P_{\alpha\alpha}^{unitary} - 2X_\alpha[1 - 2|U_{\alpha 3}|^2 \sin^2 \Delta_{31}] + X_\alpha^2.$$

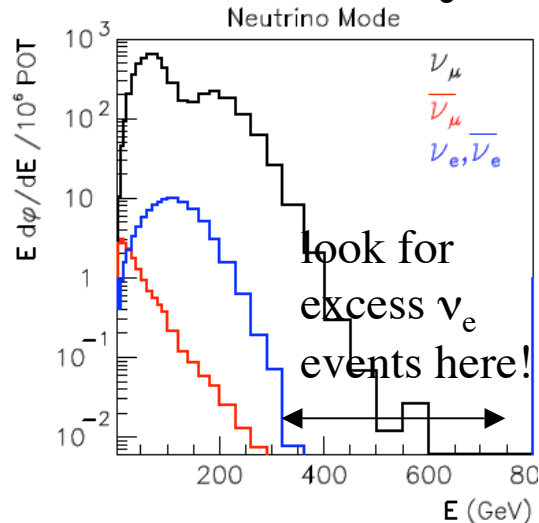
L/E dependent

Not!

Appearance has same effect!

At  $L=0$  there will be an instantaneous transition  
between neutrino species!

- Look for excess  $\nu_e$ 's in a range not expected



To see instantaneous  $\nu_\mu \rightarrow \nu_e$   
look for an increase  
in  $\nu_e$  rate at  $E_\nu \sim 350$  GeV

Seeing both  
would be a  
striking  
signature!

- Look for “wrong sign” IMD

$\bar{\nu}_\mu + e^- \rightarrow \mu^- + \bar{\nu}_e$  -- this should not occur!

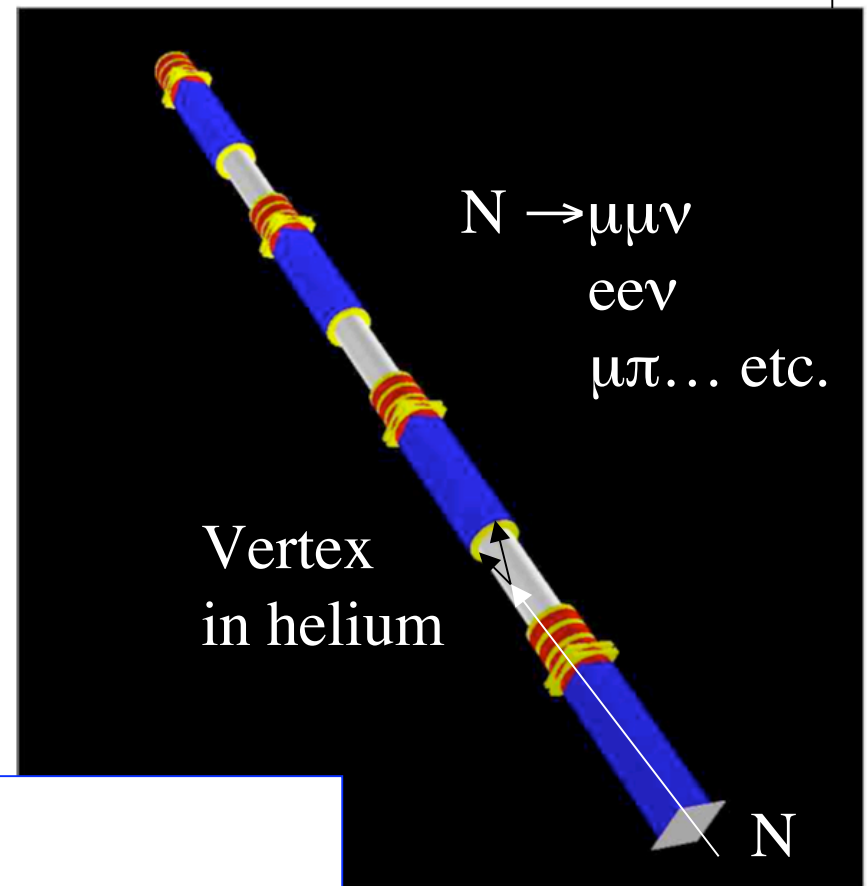
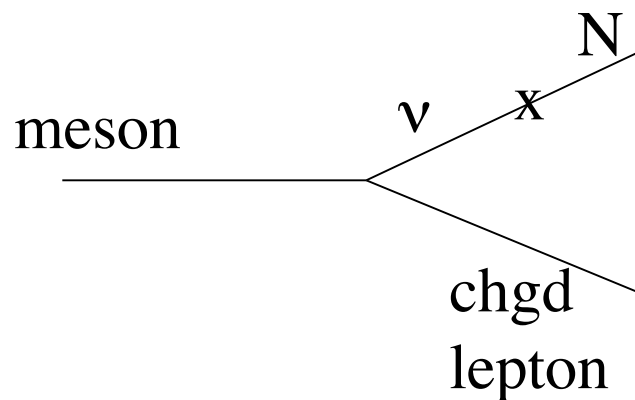
But if  $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ , then  $\bar{\nu}_e + e^- \rightarrow \mu^- + \bar{\nu}_\mu$  ... same signature!

*Unique  
Capability!*

Also a direct search:

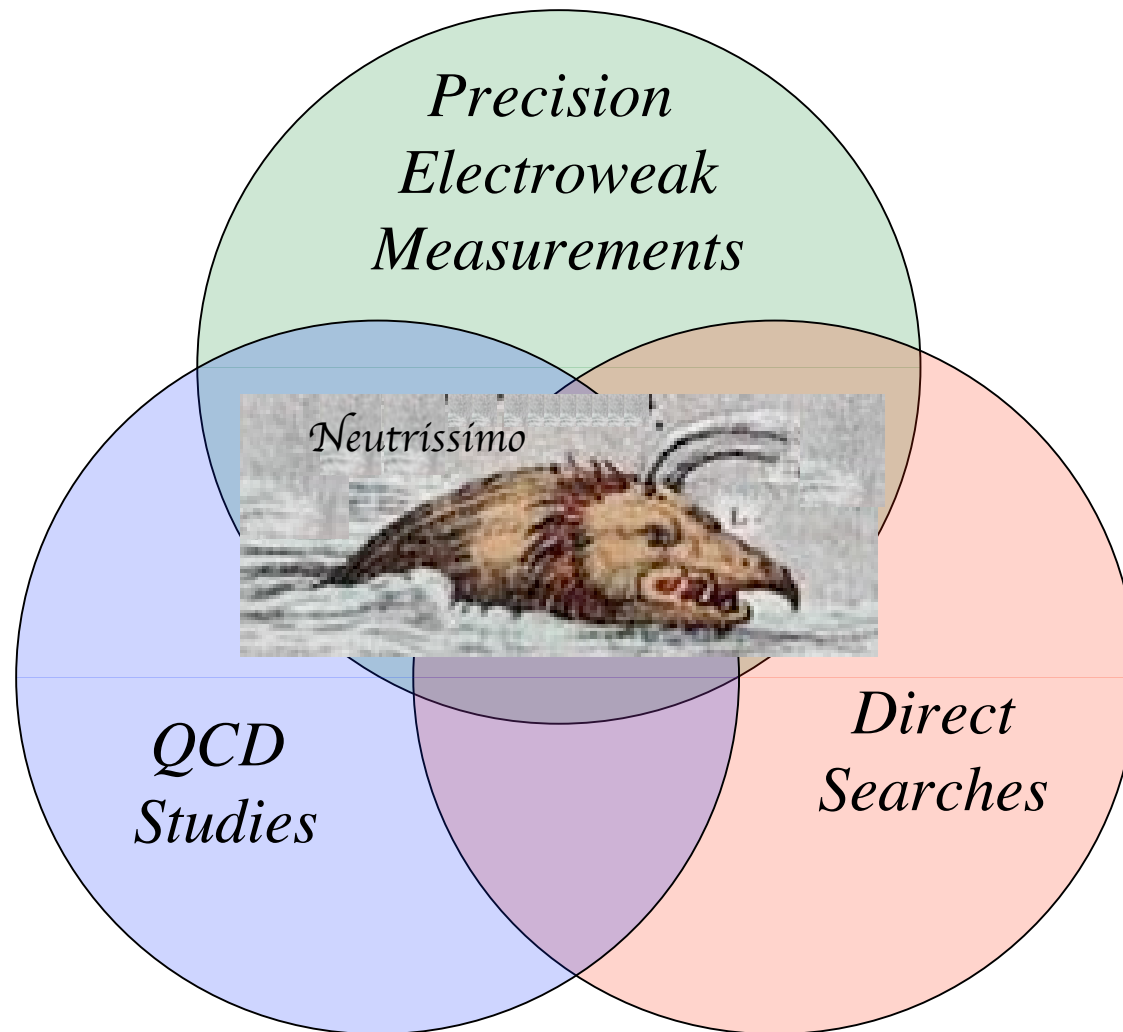
Filling the 15 m region between subdetectors with helium and looking for neutrino decays...

These are produced through mixing in meson decays:



Because of the TeV-based beam, NuSOnG search for production in B-decay... i.e. up to  $\sim 5$  GeV!

This is one example of how, by putting all of the pieces together,  
we could decisively discover new Terascale physics



## Conclusions

The purpose of this talk has been to clarify/expand upon the Terascale physics reach of NuSOnG

Our approach has been to write a PRD which is on the arXiv. This paper considers broad classes of models & specific examples

- The mass reach is  $\sim 5$  TeV for many examples.
- Some measurements are competitive with the best limits.
- Many measurements improve substantially on the present limits.
- Certain topics -- especially neutrino couplings -- are unique.
- The entire program coordinates to allow discovery.

## Next steps:

### 1) Talks at many venues:

Fermilab Wine & Cheese, May 9, André de Gouvêa

*NuSOnG: Looking for Heavy and Light New Physics  
In High-Energy Neutrino Scattering*

and...Neutrino08, PPC, DIS, NuFact, Pheno, APS (our two grad students),  
CERN, Cornell, Columbia, SLAC, Fermilab Beams Divisions... etc.

### 2) Write a paper on the QCD physics case

*This will answer PAC question #2*

### 3) Develop an LOI

*which examines physics-return for various design options*

## Back-up Slides

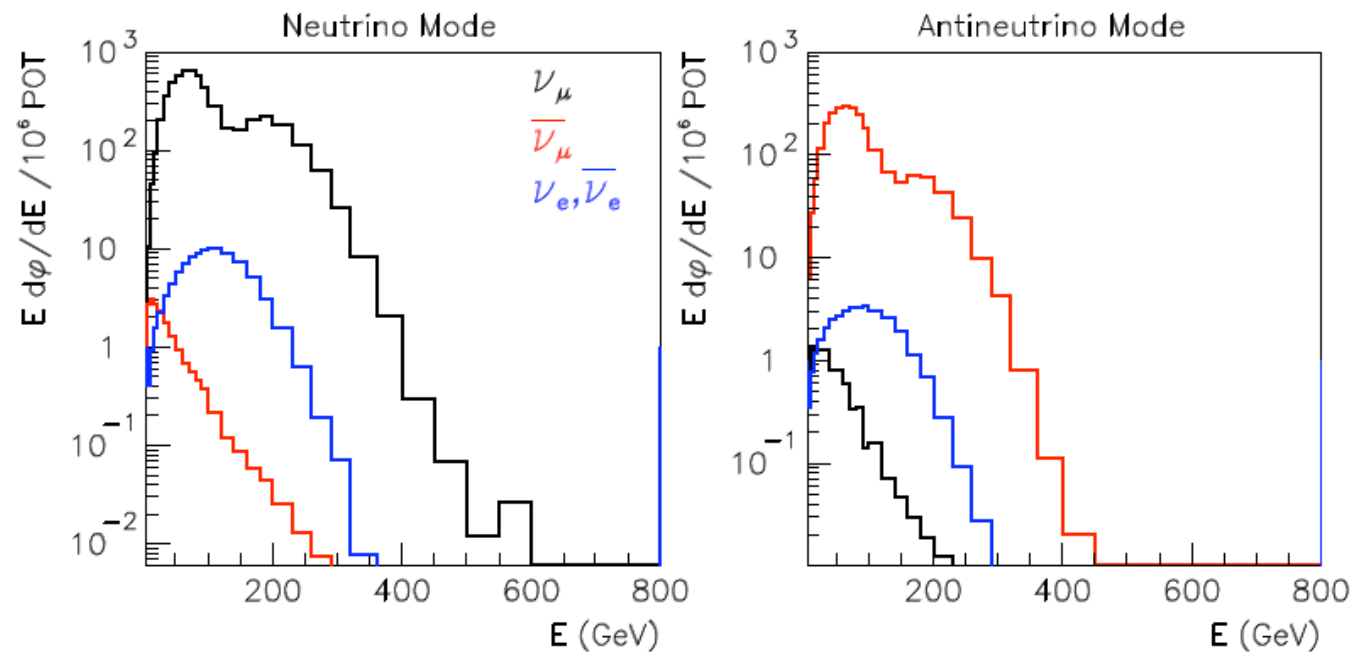
Answer to Pier Oddone's Question:

**....is there anything else that you can think of that  
could be run along NuSOnG...?**

The 800 GeV Neutrino Program can provide two beams...

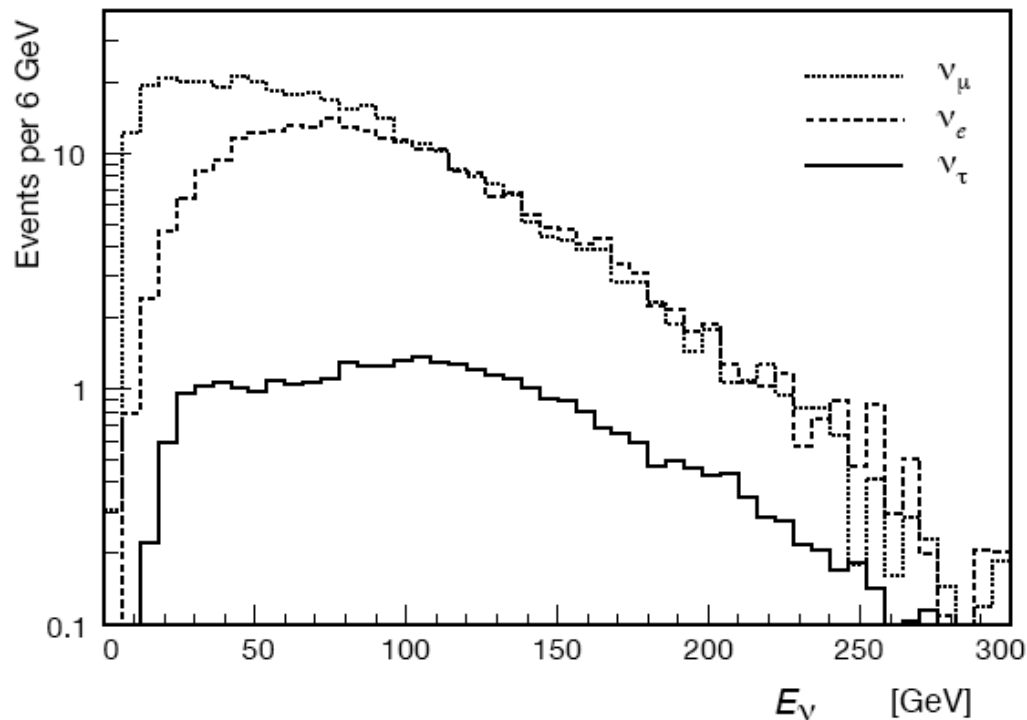
Beam 1: A NuTeV-style Flux (used by NuSOnG)

Uniquely high energy, and low background,  
produced using a sign-selected quad-train



## Beam 2: A DoNuT (Discovery of the Nu Tau)-style Flux

A beam dump flux:



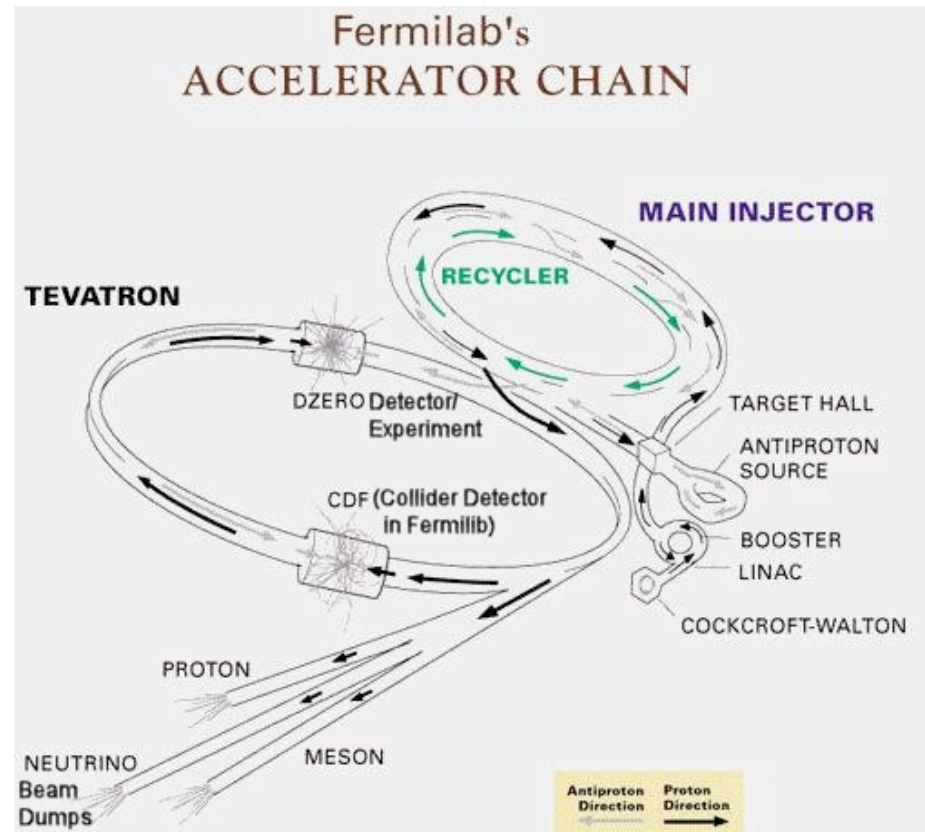
Uniquely enriched  
in  $\nu_\tau$ 's which are above  
threshold for CCQE

A Tev-based program is the only source of  
High purity  $\nu_\mu$  beams at high energies  
Enriched  $\nu_\tau$  beams at high energies

$$5 \times 10^{19} \text{ POT/year}$$

5× the number of protons  
per fill,  
1.5 × faster cycle time  
66% uptime per year

The goals were set in  
consultation with the  
Tevatron department  
to be ambitious but not  
outrageous.



Two useful publicly-available memos:

<http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=2222>

<http://beamdocs.fnal.gov/AD-public/DocDB/ShowDocument?docid=2849>

A suite of interesting experiments:

- NuSOnG
- A small  $\nu_\tau$  experiment to obtain  $\times 100$  DoNuT statistics
- A large ( $\sim 5$ kt) magnetized LAr detector for  $1\text{E}6$   $\nu_\tau$  events and neutrino factory measurements
- A small dedicated search for neutrissimos (moderately-heavy neutral heavy leptons)
- A high resolution neutrino scattering experiment to study charm and QCD (HiResMuNu)

None of these experiments can be done anywhere else.

This program is unique to Fermilab.

These are...

“near term experiments that can be supported by an evolution of the Fermilab accelerator complex”

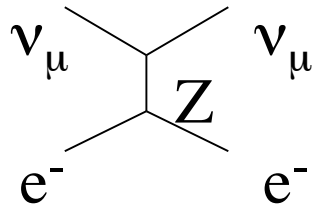
This is not a long term solution to Fermilab's Future.

**But** it is a nice bridge program to the future with

- interesting and substantial physics output
- potential to support many users
- capability to further important detector R&D goals

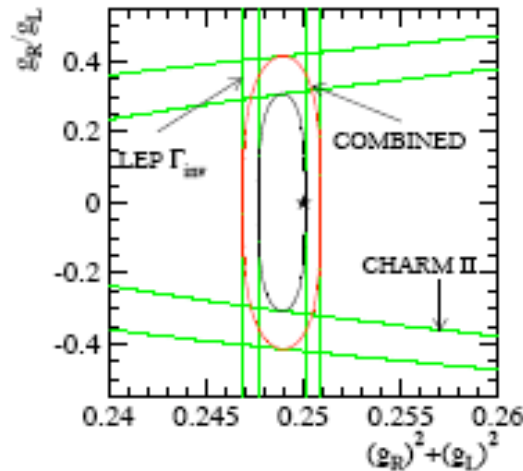
More NuSOnG Physics, described in paper,  
already presented at autumn, 2007, PAC meeting

# Probing right handed couplings of the neutrino to the Z



Present

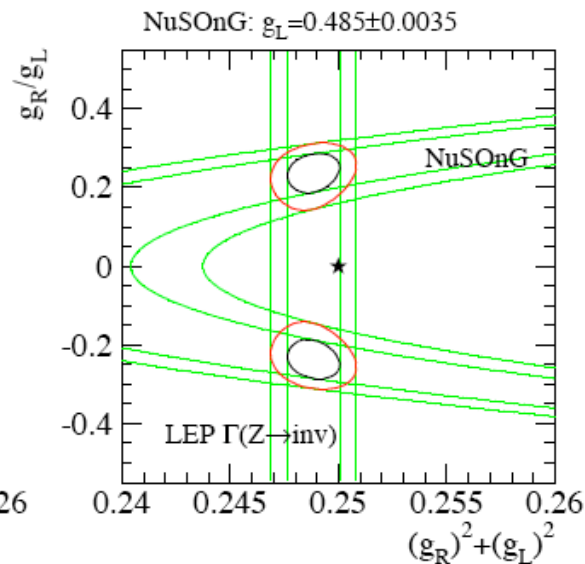
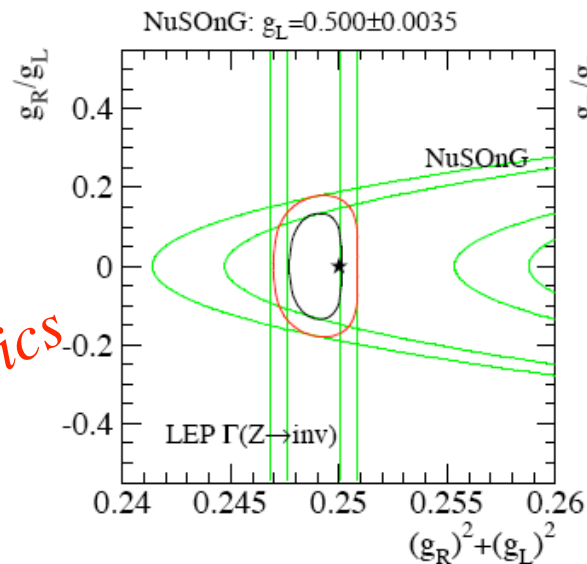
NuSONG



In the case of agreement...

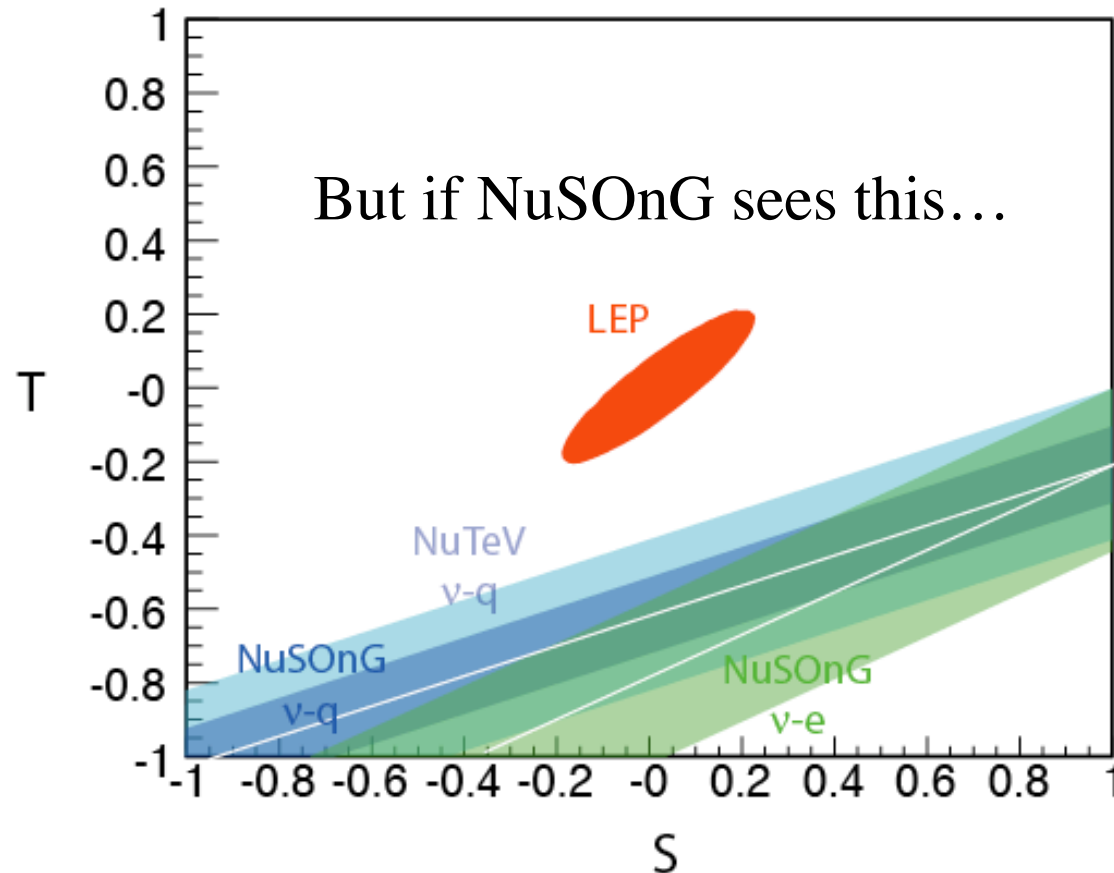
and disagreement.... with SM

*A unique  
probe of  
new physics*



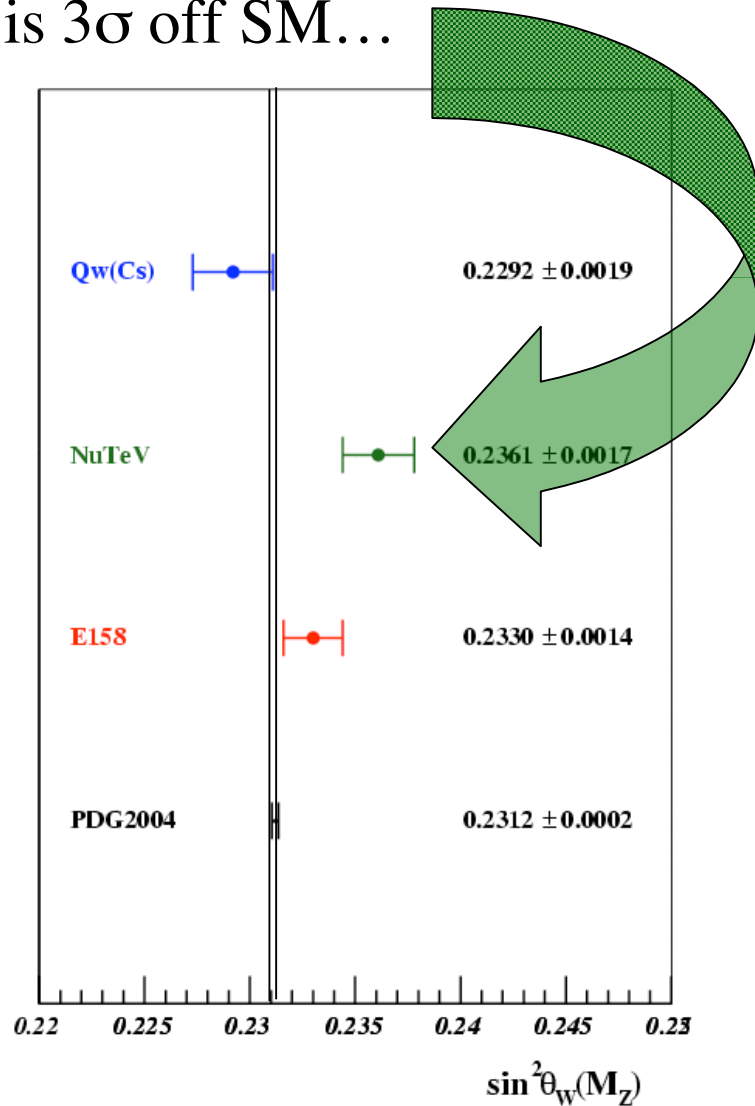
## The “God-forbid” Scenario

LHC sees a standard model Higgs and no signs of new physics

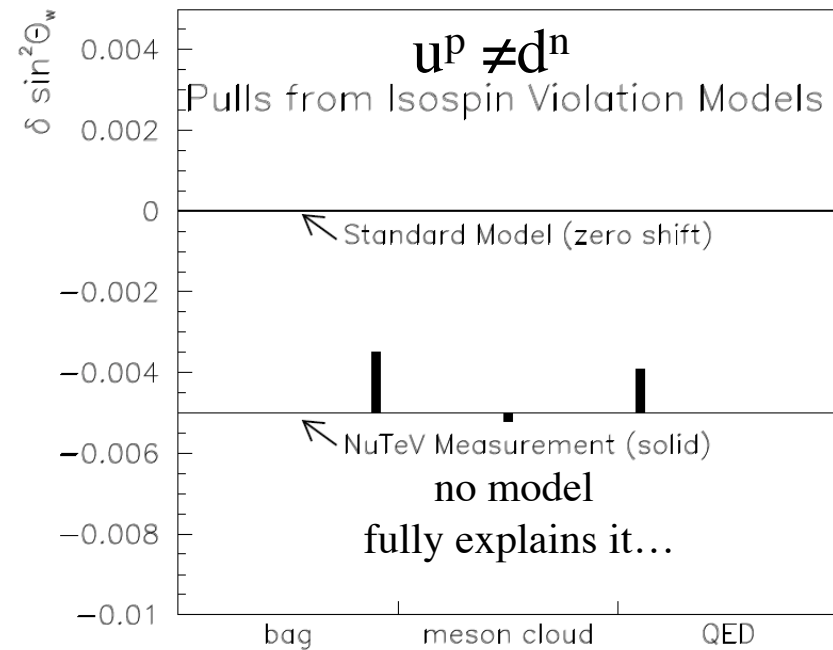


There is new physics in the neutrino sector!

NuTeV:  $\nu q$  scattering (“PW”) is  $3\sigma$  off SM...



New Physics,  
e.g. nonuniversality?  
or  
“Standard Model”?



An updated NuTeV analysis  
will be available spring/summer

New in this talk...  
Extra info.

How do you choose which Heavy Z' Models?

Useful papers defining “the standard cases”...

**Z-prime Gauge Bosons at the Tevatron**, hep-ph/0408098

Marcela Carena, Alejandro Daleo, Bogdan A. Dobrescu, Tim M.P. Tait

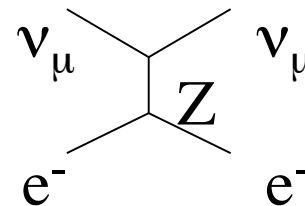
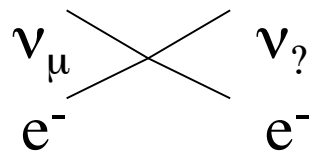
**The Physics of Heavy Z' Gauge Bosons**, hep-ph/0801.1345

Paul Langacker

Why is the mass-scale sensitivity lower for  
 $\alpha \neq \mu$  compared to  $\alpha = \mu$  ?

$$\mathcal{L}_{\text{NSI}}^e = + \frac{\sqrt{2}}{\Lambda^2} \left[ \bar{\nu}_\alpha \gamma^\sigma P_L \nu_\mu \right] \left[ \cos \theta \bar{e} \gamma^\sigma P_L e + \sin \theta \bar{e} \gamma^\sigma P_R e \right]$$

The sensitivity to this term comes from interference  
 between this diagram... and this diagram....



You will have a larger interference term  
 if the final state is identical ( $\alpha = \mu$ )  
 compared to not ( $\alpha \neq \mu$ )

*The larger the interference, the higher the sensitivity!*

Fitting for nonuniversal couplings:

One fits to S,T and the couplings, simultaneously:

Present status

$$\begin{aligned} S &= -0.05 \pm 0.11 , \\ T &= -0.44 \pm 0.28 , \\ \epsilon_e &= 0.0049 \pm 0.0022 , \\ \epsilon_\mu &= 0.0023 \pm 0.0021 . \end{aligned}$$

With NuSOnG

$$\begin{aligned} S &= 0.00 \pm 0.10 , \\ T &= -0.11 \pm 0.12 , \\ \epsilon_e &= 0.0030 \pm 0.0017 , \\ \epsilon_\mu &= 0.0001 \pm 0.0012 . \end{aligned}$$

Why can't this be done on a MI line  
(NuMI or DUSEL)?

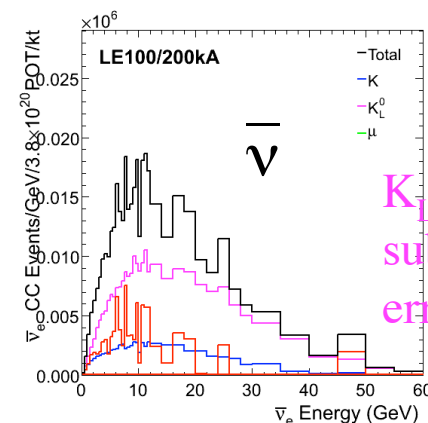
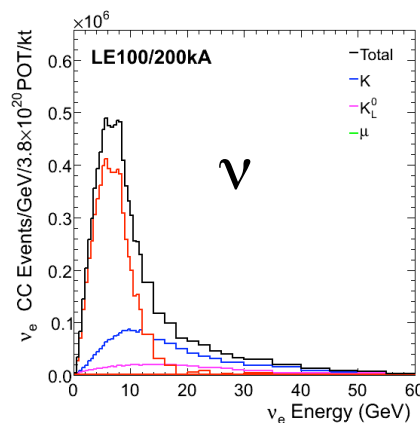
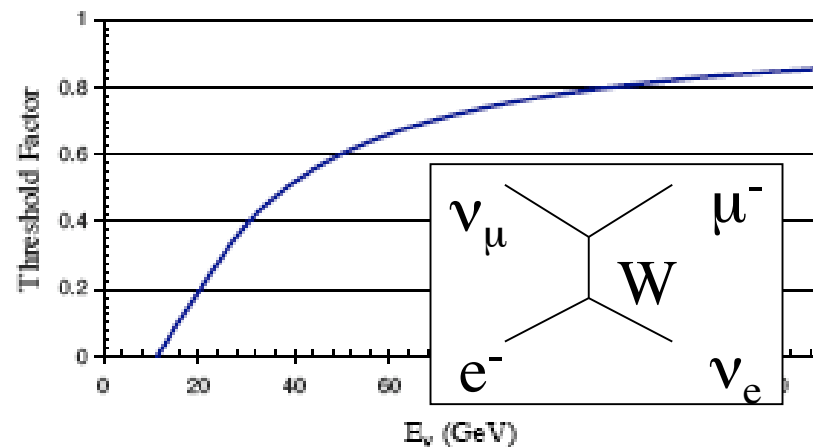
Problem 1: Statistics.

Even in the best Project X scenarios 5-10 year runs  
yield about 15-20k event before cuts.

Problem 2: Normalization

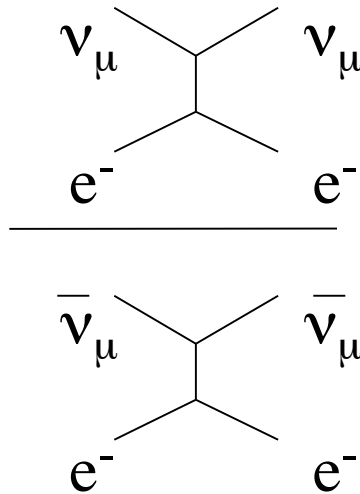
IMD Normalization  
is not possible

You must use  
the  $\nu_e/\bar{\nu}_e$  ratio,  
but fluxes don't  
perfectly cancel.  
<1% error will be very hard!



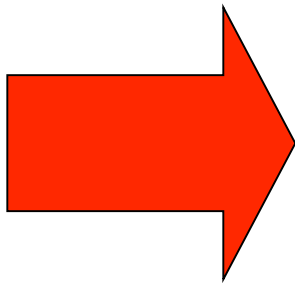
$K_L^0$  has a  
substantial  
error.

Problem 3:  $\nu_e/\bar{\nu}_e$  ratio cancels  $\rho$  -- which removes access to a lot of the BSM physics we want to investigate!



$$\sigma(\nu_\mu e) = \frac{G_F^2 m_e E_\nu}{2\pi} \rho^2 \left[ 1 - 4 \sin^2 \theta_W + \frac{16}{3} \sin^4 \theta_W \right]$$

$$\sigma(\bar{\nu}_\mu e) = \frac{G_F^2 m_e E_\nu}{2\pi} \frac{\rho^2}{3} \left[ 1 - 4 \sin^2 \theta_W + 16 \sin^4 \theta_W \right]$$



You get a lot less physics for a much more difficult experimental program.